A Simulation Analysis of the Time-Dependent Roles of Phytoplankton and CDOM in Effecting the 3-Dimensional Structure of Inherent Optical Properties on the West Florida Shelf

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Grant Number N000149910212

LONG-TERM GOAL

Construction and validation of coupled physical/ecological/bio-optical models of phytoplankton, colored dissolved organic matter, and suspended sediments on continental shelves to predict both the time-dependent, spatially-heterogeneous inherent optical properties [IOP] of subsurface waters and the consequent hyperspectral water leaving radiances [L_w] at the surface.

OBJECTIVES

Using the West Florida shelf as an initial test case, where field validation data are now being obtained in the ONR HyCODE [Hyperspectral Coastal Ocean Dynamics Experiment], ONR AUV [Autonomous Underwater Vehicle]-Sensor, and NOAA/EPA/ONR ECOHAB [Ecology and Oceanography of Harmful Algal Blooms]:Florida projects, my objective is to couple a model of seven functional groups of competing microalgae to ones of both physical forcing at different regional/local scales and of the consequent bio-optical signals sensed by aircraft and satellites.

These ONR studies focus on a control volume, now bounded by ADCP arrays, which extends between the 10-m and 50-m isobaths, along the Florida coast from Tampa Bay to Charlotte Harbor, and is sampled at monthly intervals with continuous underway measurements of u, v, temperature, salinity, *in vivo* chlorophyll fluorescence, CDOM, and transmissometry. At discrete stations, additional data are now collected on distributions of NO_3, NO_2, PO_4, SiO_4, Fe (III), DOP, DON, DIC, DOC, CDOC, chlorophyll, phaeopigments, PN, PC, PP, del^{15}N of PN and NO_3, cell counts of all dominant phytoplankton species, and abundances of microzooplankton and macrozooplankton species.

During the coming year, additional interior ADCP arrays of the control volume will support a suite of moored optical sensors: hyperspectral radiometers, backscatterometers (660 and 880 nm), c-meters (288 and 660 nm), and fluorometers (chlorophyll and CDOM). On supplemental cruises at 2-month intervals, other discrete measurements of turbidity, and spectral dependence of absorption, backscatter, water-leaving radiance, and light attenuation will be made. Finally, during two AUV experiments in summer and fall of 2000, SF_6 dispersion studies are planned in relation

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **A Simulation Analysis of the Time-Dependent Roles of Phytoplankton and CDOM in Effecting the 3-Dimensional Structure of Inherent Optical Properties on the West Florida Shelf**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of South Florida,Department of Marine Science,140 Seventh Ave. South,St. Petersburg,FL,33701**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

to aircraft overflights and underway sampling of plankton particles [OPC, LS] and images [SIPPER]. In anticipation of numerical synthesis of these diverse data sets, we have begun retrospective simulation studies of the biological and chemical sources of IOP and L_w over the last 40 years on the West Florida shelf.

APPROACH

A traditional N-P-Z [Nutrient-Phytoplankton-Zooplankton] model with one state variable each to represent the plant and animal communities of oceanic waters is incapable of addressing bio-optically complex regions of the coastal zone, where competing functional groups of plankton on the West Florida shelf, for example, may all generate separate pigment stocks of >5.0 µg chl l^{-1}, i.e. spectrally-averaged attenuations of >.09-.29 m^{-1} depending upon packaging effects of cell size, in both the water column (Fig. 1a) and the sediments. In this subtropical habitat, diatoms, microflagellates [M], toxic dinoflagellates [D], nitrogen-fixing cyanophytes [C], and benthic microflora each form episodic blooms, whose changing color signals are derived from physical supply of nutrients, aggregation processes, and differential losses of the algal populations. Riverine supply of terrestrial humic and fulvic acids, plankton release of marine CDOC, and local resuspension of organic and inorganic debris (Fig. 1e) further complicate interpretation of remotely-sensed L_w.

With this goal of specification of IOP and L_w over time and space, the above field programs were designed to test a set of linked 3-dimensional circulation, phytoplankton/microflora succession, and spectrally resolving bio-optical numerical models, developed by a group of ONR-funded investigators, consisting of J.J. Walsh and R.H. Weisberg at USF [University of South Florida], R.W. Garwood at NPS [Naval Postgraduate School], and W.P. Bissett at FERI [Florida Environmental Research Institute]. Brief details of the other circulation and bio-optical models are presented in the section on related projects.

The model's state variables of the planktonic microalgal community are small and large diatoms, toxic and edible dinoflagellates, nitrogen-fixing *Trichodesmium*, coccolithophores, autotrophic microflagellates, and coccoid cyanophytes. Since chlorophyll biomass within the upper 0.5 cm of sediments can be 2-4 fold that of the overlying water column, with a five-fold seasonal variation on the West Florida shelf, the benthic microflora are another state variable. Light [spectral PAR], nutrient availability [NO_3, NH_4, N_2, PO_4, SiO_4, Fe, DOP, DON, DIC], and differential settling or grazing [heterotrophic flagellates, ciliates, copepods, meiobenthos] losses effect the outcome of competition and release of CDOC among the 7 groups of microalgae.

WORK COMPLETED

In collaboration with K.A. Steidinger of the Florida Fish and Wildlife Conservation Commission [FWCC], K.A. Fanning and G.A. Vargo of USF, ~40 years of phytoplankton, nutrient, and hydrographic observations on the West Florida shelf have been compiled as different time series over 1957-1961, 1964-1968, and 1971-1998 to develop and initialize the above plankton model,

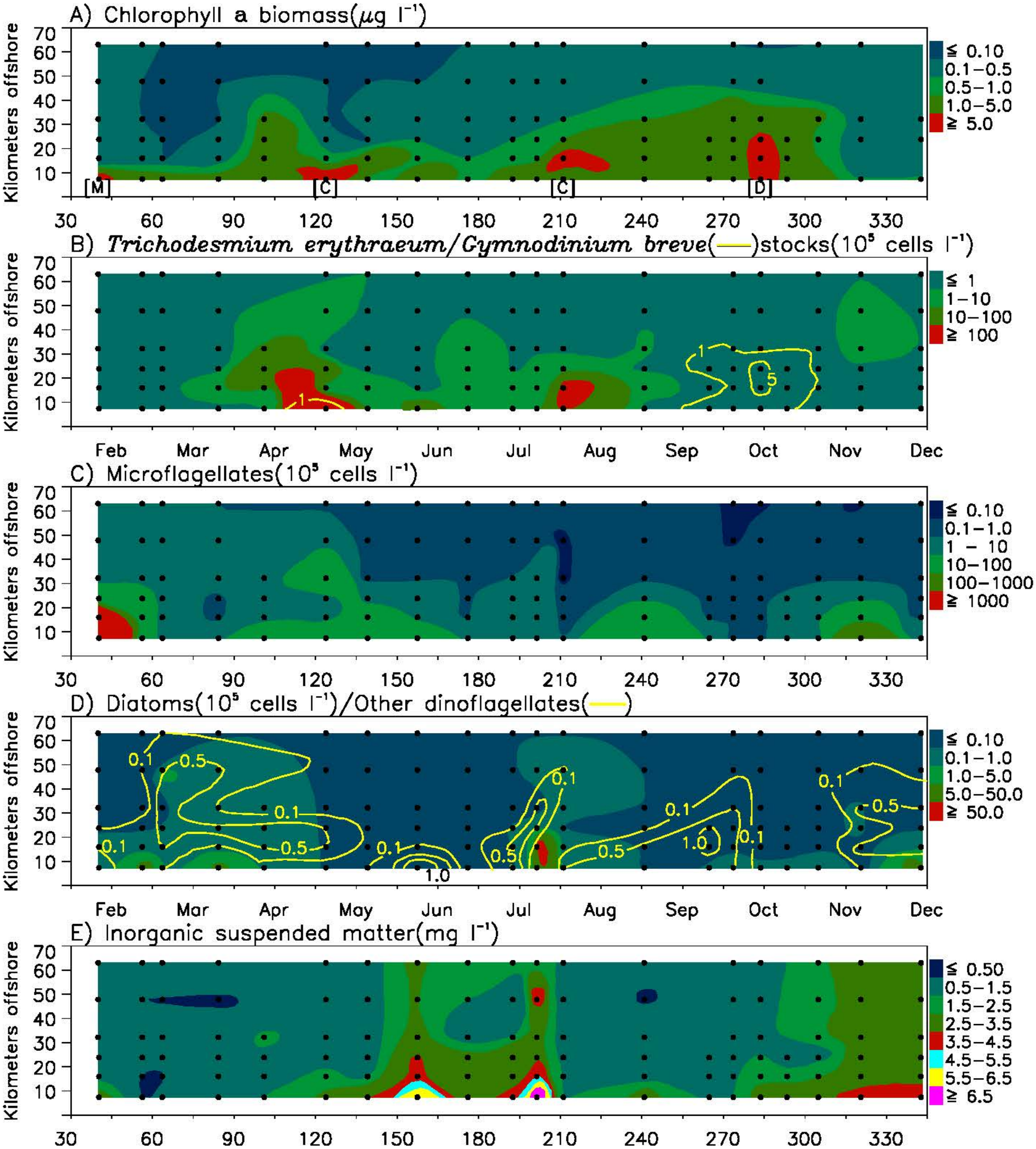

Figure 1. Surface distributions of A) chlorophyll a($\mu g\ l^{-1}$), B) *Trichodesmium erythraeum and Gymnodinium breve* (10^5 cells l^{-1}), C) microflagellates (10^5 cells l^{-1}), D) diatoms and other dinoflagellates (10^5 cells l^{-1}), and E) inorganic suspended matter(mg l^{-1}) across the inner West Florida shelf during 1976.

and its associated circulation and bio-optical submodels, prior to the field phase of the HyCODE project. An example of the FWCC data sets is presented as Figure 1 of biweekly sampling in 1976 of chlorophyll biomass (Fig. 1a), functional group composition (Figs 1b-d), and suspended matter (Fig. 1e) at 6 stations of a cross-self section, taken out to the 40-m isobath from the coast within the present HyCODE/ECOHAB/AUV control volume.

RESULTS

Since, we have just begun this research, it is premature to discuss results. However, we can address which hypotheses we are testing in these retrospective simulation analyses. Based on Loop Current influxes of nitrate from the shelf-break during USFWS cruises in 1958-1961 and estuarine discharges of this form of nitrogen from the Apalachicola and Suwannee Rivers during FWCC Coastal Production cruises in 1992-1993, 1) pelagic diatoms outcompete the other functional groups. Fallout of the poorly-grazed spring bloom of diatoms during the 1996 Florida Shelf Lagrangian Experiment [FSLE] 2) leads to sequestration of remineralized ammonium by benthic microflora, rather than to sediment effluxes for support of another bloom in the water column, except for episodic resuspension events (Fig. 1). Such an indirect nutrient loading 3) triggers seasonal increments of sediment chlorophyll here and on the Georgia shelf, possibly impacting bottom reflectance.

During the FWCC Hourglass cruises in 1965-66 and Remote Sensing cruises in 1976 (Fig. 1), blooms of *Trichodesmium* preceded those of toxic and edible dinoflagellates. In response to alleviation of summer Fe-limitation by atmospheric supplies of Saharan dust (Walsh and Steidinger, 1999), 4) excretion of DON by these nitrogen-fixers fuels the subsequent fall dinoflagellates blooms. Ten-fold variation of copepod grazers during 1966 and 1967 leads 5) to selective grazing pressure on the other dinoflagellates, ensuring blooms of the slower growing, toxic *Gymnodinium breve*, when copepods are abundant. Once established after another *Trichodesmium* bloom in 1986, vertical movements of *G. breve* in relation to stratification of the water column during another FWCC cruise 6) determine whether near-bottom or near-surface populations are entrained by onshore currents. Concurrent CZCS imagery and FWCC cruises suggest that 7) an upwelling circulation mode in fall 1979 leads to smaller bio-optical signals of red tides near the coast than during a downwelling mode in 1980. Finally, all the smaller size classes of phytoplankton are held down by grazing stresses of the heterotrophic flagellates and ciliates, with 8) occasional blooms of the microflagellates (Fig. 1) stimulated by prey-switching of copepods to the larger ciliates, but not to the smaller heterotrophic flagellates.

IMPACT/APPLICATIONS

Once these coupled models of IOP and L_w are validated for the West Florida shelf site, we would apply them to other ongoing ONR field studies: COBOP at Lee Stocking Island in the Bahamas and LEO-16 on the New Jersey shelf.

RELATED PROJECTS

With support from N000149810158, Bob Weisberg of USF is responsible for the application of a primitive equation model at 5-km resolution to an analysis of the observed current fields on the West Florida shelf. The physical circulation model is an adaptation of the Princeton Ocean Model [POM] that employs a topography- following sigma coordinate system in the vertical and an orthogonal curvilinear coordinate system in the horizontal - a number of publications have just appeared in *Journal of Geophysical Research* and *Continental Shelf Research*. Far-field forcing at the shelf-break is also being examined with the results of a larger mesh model for the Gulf of Mexico basin, using the output from the present Dynalysis circulation model.

With support from N000149615024, Roland Garwood of NPS is using a non-hydrostatic Large Eddy Simulation [LES] model to compute small scale flows within the POM grid cells, since it is at the turbulence integral scale that physical processes accomplish most of the vertical mixing and dispersion of nutrients and plankton. Over an imbedded isotropic grid of order 1-4 m, the LES model solutions will be brought to statistical quasi-steady state for a variety of conditions in the Ro, Ri parameter space. In particular, Lagrangian drifters and inert neutral tracers will be included in a conservative numerical scheme as part of the coupled simulations of concurrent biochemically active tracers during different seasons of the year.

With support from N000149810844, Paul Bissett of FERI is applying Ecological Simulation 2.0 [EcoSim 2.0.] to the West Florida shelf. His code includes the living and non-living particle specific optical properties, as well as the optical properties of colored dissolved matter to effect the daily changes in the spectral quality of the downwelling light field. The daily IOP outputs are also coupled with the Hydrolight 4.0 radiative transfer code to predict the upwelling light field at 10:00 am each day. We are merging POM, LES, and EcoSim 2.0 with the microalgal succession submodel described above to form a complete 3-dimensional, ecologically complex, bio-optical model of the West Florida Shelf.

PUBLICATIONS

Walsh, J.J. and K.A. Steidinger. 1999. Saharan dust and Florida red tides: the cyanophyte connection. Nature (Submitted).